Glaciers and Nutrients in Arctic Seas

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Abstract

Significantly higher concentrations of dissolved inorganic nitrate and silicate were found in the waters of glaciated South Cape Fiord than in unglaciated Grise Fiord, Ellesmere Island, N.W.T., or in adjacent Jones Sound. No significant differences in phosphate concentrations were found. Glacial activity apparently enriches the concentrations of those nutrients most critically limiting for arctic phytoplankton requirements.

Introduction

The effects of active, moving glaciers discharging into the sea upon the nutrient content of adjacent waters has been the subject of some limited speculation. Vibe (1939), for example, discussing conditions in Northwest Greenland, remarked "... I hold the view that the glaciers far surpass precipitation as an erosive factor in procuring the inorganic material ... which renders all organic life possible."

Similarly Sverdrup (Cooper, 1952, p 520) "... suggested that Antarctic waters should also receive much dispersed silica formed by communition of rock beneath the very large glaciers of the Antarctic continent."

The possibility exists, then, that glacial activity may be a significant source of nutrients for phytoplankton requirements in polar seas.

In May, 1969, I collected water samples in the Canadian Arctic to test the hypothesis that active glaciers enrich nutrient concentrations in the sea. This report describes the results of that work.

Description of the Area

This work was carried out in two of the numerous fiords that indent the southern shore of Ellesmere Island, N.W.T. (Fig. 1). Grise Fiord extends inland approximately 24 miles (38 km) and does not have any glaciers reaching its shores. South Cape Fiord is

approximately 15 miles (25 km) long and has three glaciers (Fig. 2) reaching its shores. The largest of these, unnamed, is approximately 20 miles (32 km) long and about 2 miles (3.2 km) wide where it reaches the fiord. This glacier evidently is active, calving small icebergs into South Cape Fiord. Figure 2 clearly shows one such berg recently calved from the glacier front. In May, 1969, at least 15 icebergs were frozen into the fiord.

At the time of this survey air temperatures were in the range of 5° - $30^{\circ}F$ and the entire area was snow-covered with no signs of spring thaw or melt. There were no effects on the sea of run-off from the land. Snow depths on the sea ice in Grise Fiord were variable from a few inches (± 10 cm) up to two feet (60 cm) and the snow was generally wind-packed, making travel easy. In South Cape Fiord, however, soft, loose, unconsolidated snow averaging about 2 feet (60 cm) in depth, made traveling slow and tedious and prevented us from reaching the glaciers at the head of the fiord.

The nearest ice-free open water was approximately 35 miles (55 km) south east of the mouth of Grise Fiord, lying east of the normal edge of fast ice which runs in a concave line from near Ward Point, Devon Island ($82^{\circ}20'$ W, $75^{\circ}53'$ N), toward King Edward VII Point, Ellesmere Island. West of that line, and throughout the area of this study, Jones Sound and adjacent waters were completely covered with intact, snow-covered sea ice.

The ice in Grise Fiord averaged about 3.5 feet (± 1 m) thick. In South Cape Fiord, however, the sea ice was only 2.5 - 3.0 feet (0.75 - 0.9 m) thick because of the deeper snow cover.

Grise Fiord has a maximum depth of about 365 m inside a sill depth of about 135 m. South Cape Fiord appears to be quite shallow

in comparison. Three soundings (Stations 5, 6, 7) showed depths of 87, 67 and 77 meters. Jones Sound is 500 - 600 m deep in the area of our stations.

Geologically, the two fiords are similar (Geological Survey of Canada, 1962). Cambrian, Ordovician and Silurian dolomites, limestones and sandstones surround both fiords, except just at the mouth of Grise Fiord where granitic "quartz-feldspar-biotite gneiss" is exposed. The glaciers in South Cape Fiord lie in the same dolomite and limestone beds that surround the two fiords.

Methods

We traveled over the sea ice by motor tobogan, towing a komatik loaded with equipment. Four stations were occupied in Grise Fiord, and three in South Cape Fiord (Fig. 1). Two stations were made in Jones Sound, south of Grise Fiord, for comparison with conditions in the fiords. Seal holes through the ice were used at Stations 1 and 7. A narrow refrozen lead was found at Station 8 in Jones Sound. At the other stations holes were cut with a hand augur.

At each station standard depths were sampled by Nansen bottles with attached protected reversing thermometers. Temperatures were read until consistent readings were attained at equilibrium and then recorded and subsequently corrected to the in situ temperatures. The samples were drawn from the Nansen bottles in a tent heated when necessary to prevent freezing at the stop cocks.

Salinity samples were stored separately in glass bottles and determined by the Woods Hole Oceanographic Institution. Samples for nitrate and phosphate determinations were stored in glass

in sandstone. Three stations (Stations 3, 4, 5) showed depths of 87, 84 and 17 meters. [illegible] depths in 100 - 200 m [illegible] the area of our stations.

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Salinity samples were stored [illegible] and later determined at [illegible]. Samples for nitrate and phosphate [illegible] were [illegible]

bottles and preserved with a solution of 5g HgCl/l added in the amount of 1 ml/250 ml of sample. Silica samples were stored in plax bottles.

It was planned to measure silicate concentrations in the Arctic, thus avoiding prolonged storage in plax bottles. The portable spectrophotometer was defective, however, upon arrival at Grise Fiord village, and so frozen silica samples were returned to Boothbay Harbor. The silica samples usually were frozen at prevailing air temperatures within a few hours after collection. The longest interval in which samples were not frozen, either by air temperatures or by the deep-freeze was about six hours in the case of Station 7, South Cape Fiord. The plax bottles were put in a deep-freeze unit immediately upon arrival at Grise Fiord village. The plax bottles were returned frozen to deep-freeze storage at Boothbay Harbor for analysis. Some slight peripheral softening occurred on the seven-hour drive from Montreal to Maine.

Nutrient concentrations were measured following the methods outlined for nitrate by Wood, Armstrong and Richards (1967), as modified by the Woods Hole Oceanographic Institution, and for phosphates and silicates by Strickland and Parsons (1968). Optical densities for nitrates, phosphates and some silicates were read on a Klett Summerson Colorimeter using appropriate filters. All silicates were initially determined on a Bausch and Lomb Spectronic 20 spectrophotometer. No salt factors were applied.

The significance of the differences of nutrients between the two fiords, between South Cape Fiord and Jones Sound, and between Grise Fiord and Jones Sound were determined by the Mann Whitney U test which does not assume the values are normally distributed

about the means. Figure 3 suggests the nutrients distribution are related to densities and are not normally distributed.

Hydrography

The physical oceanography of arctic Canada has been discussed most recently by Collin and Dunbar (1964). The waters of Jones Sound are derived from the upper layers of the Arctic Ocean, most of which arrives in the Sound from the west via Cardigan Strait and Hell Gate. A small proportion flows in from the east from Smith Sound via Glacier Strait. Bailey (1957) reported "... an eastward flow taking place in the surface layer across the section [i.e. the width of Jones Sound]. The cold water layer [of intermediate depth], however, moved westward on the north side and eastward on the south side. Movements in the deep waters, although slight were generally eastward."

Apparently no nutrient data from the archipelago channels northwest of Jones Sound have been published. McGill and Corwin (1964) present considerable data on nitrates, phosphates and silicates, together with physical observations, taken in Kane Basin and northern Baffin Bay. One line of stations began just off Glacier Strait at the northeast entrance of Jones Sound, but the data were obtained during the ice-free season early in August when nutrients in surface waters probably were depleted because of phytoplankton growth, and so they cannot be compared directly with the present values. Unfortunately, the shallow depths of South Cape Fiord prevent comparison of deeper waters below the euphotic zone.

Results

The results are given in Table 1 in which all nutrient data are given as microgram-atoms per liter. Two values are listed for silica; column (a) refers to those obtained on the spectrophotometer and column (b) lists those obtained on the colorimeter.

The results for nitrates and phosphates from Grise Fiord and Jones Sound, preserved by HgCl and stored in glass, gave unequivocal and reproducible results comparable with those obtained by the author in 1961-1963 in Jones Sound and Grise Fiord (unpublished data) and with those reported by McGill and Corwin (1964) from the deeper waters of northern Baffin Bay and Kane Basin.

The silicate results from samples frozen in plax bottles, however, are more variable and contain some uncertainties. Phosphate analysis (not listed here) on those samples showed similar variability, and Richards and Vaccaro (1956) remarked "... experience has shown that phosphates determined on frozen samples are somewhat erratic." It is believed that problems in this project were caused by partial and variable adsorption onto the plax bottles.

It is probable that insufficient shaking of the sample on the first analysis, Table 1, Column a, released only part of the adsorbed silica. It is also probable that the amount of adsorbed silica was proportional to the total quantity in the sample. More vigorous shaking on the second analyses (Column b) probably released proportionalely more silica; thus the values in Column b are generally higher than those in Column a, and the generally higher values of South Cape Fiord seemed to increase relatively more than those of Grise Fiord and Jones Sound. The true silica values probably lie between those of Columns a and b.

In comparing nutrient concentrations with those in South Cape Fiord, only data from 0-75 m in Grise Fiord and Jones Sound were used since the maximum observed depth in South Cape Fiord was 87 m. Similarly, the data from 0-200 m in Jones Sound were compared with all those in Grise Fiord.

There is no significant difference in phosphate concentrations between the two fiords or between each fiord and Jones Sound.

Nitrates, in contrast, show significantly larger concentrations in South Cape Fiord than in Grise Fiord ($U = 3.88$, $P < 0.001$), and in Jones Sound ($U = 2.50$, $P < 0.01$). There is no significant difference between Grise Fiord and Jones Sound ($U = 1.153$, $P > 0.05$).

Silicates average higher in South Cape Fiord than in Grise Fiord. It is not certain that the difference is significant, however. The first analysis of 40 samples (18 from South Cape and 22 from Grise Fiord), carried out on the spectrophotometer showed that silica averaged 18.8 µg A/l in South Cape Fiord and 16.2 µg A/l in Grise Fiord, but the difference is not quite significant. A second analysis of 27 samples (13 in South Cape and 14 in Grise Fiord) on the colorimeter, however, showed silica averaged 21.3 µg A/l in South Cape Fiord and 17.1 µg A/l in Grise Fiord. This difference is highly significant ($U = 2.609$, $P < 0.01$).

As noted earlier, differential adsorption probably reduced the apparent concentrations of silica in the first set of analyses with proportionately greater reductions in the apparently higher concentrations of South Cape Fiord.

It is probable that the silica concentrations in South Cape Fiord, like the nitrate concentrations, in fact are significantly greater than those in Grise Fiord and Jones Sound.

[illegible]

[illegible]

Standard grading [illegible]

[illegible]

Discussion

These results strongly suggest that glacial discharge in South Cape Fiord does increase the concentrations of nitrates and silicates in the sea adjacent to the glacier. The probable increase in silica is not surprising and was anticipated in planning this survey but the nitrate increase is unexpected.

The author carried on measurements of phosphates and silicates in the summers of 1961, 1962 and 1963, and of nitrates in 1962 and 1963, on the south side of Jones Sound throughout the periods of phytoplankton development. In each summer (eg 1962; Table 2) phosphates showed relatively little depletion but nitrates were completely exhausted in and below the euphotic zone, and the plant cells exhibited symptoms of nitrate deficiency (unpublished data). Silica was substantially reduced each year, but was not completely exhausted. It is thus interesting to note that those two nutrients in critical supply for phytoplankton development in arctic waters are those which appear to be augmented by glacial activity, at least in South Cape Fiord.

Acknowledgements

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FIGURE 1

The locations of oceanographic stations made in waters off southern Ellesmere Island, NWT, Canada, May 1969.

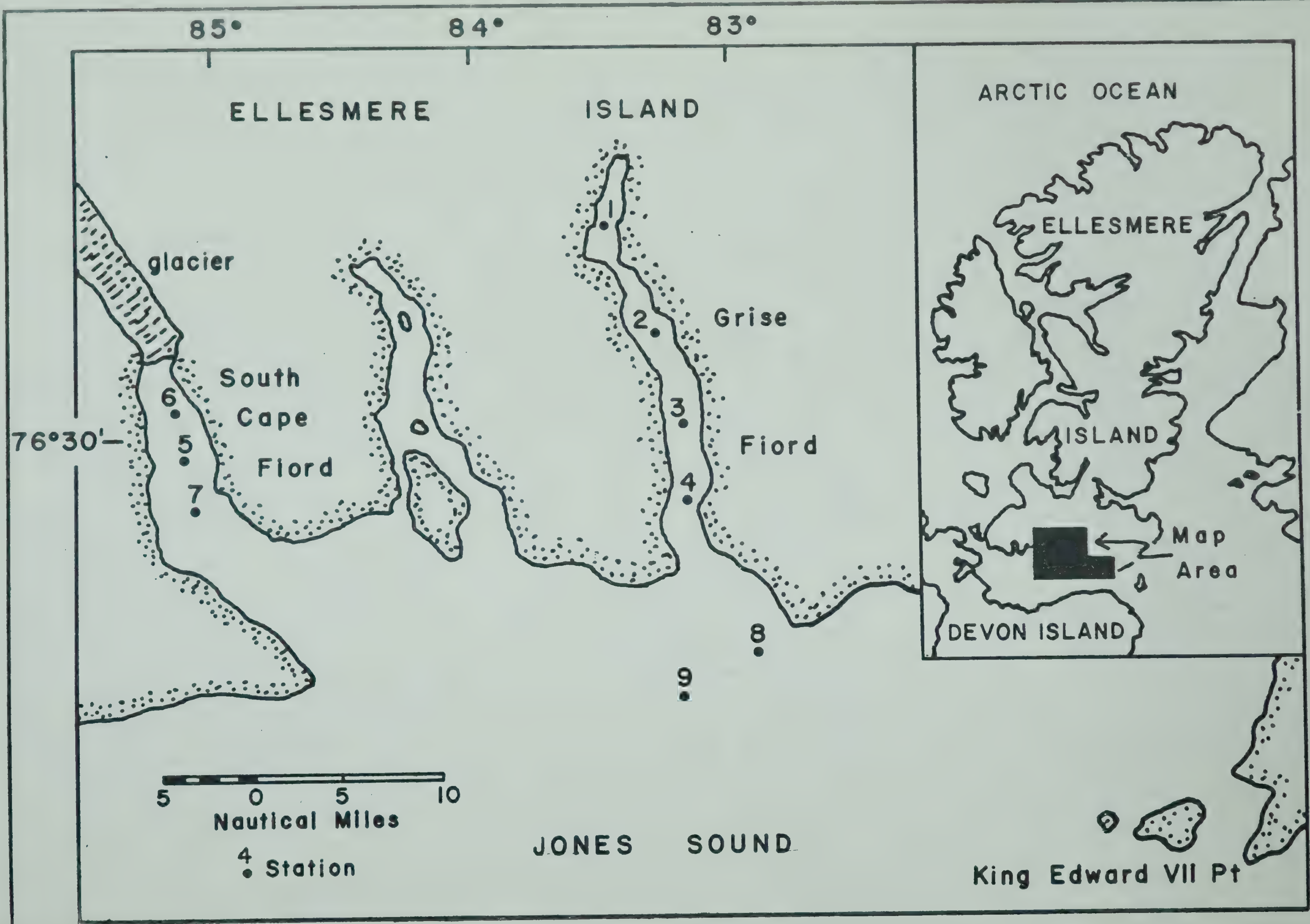
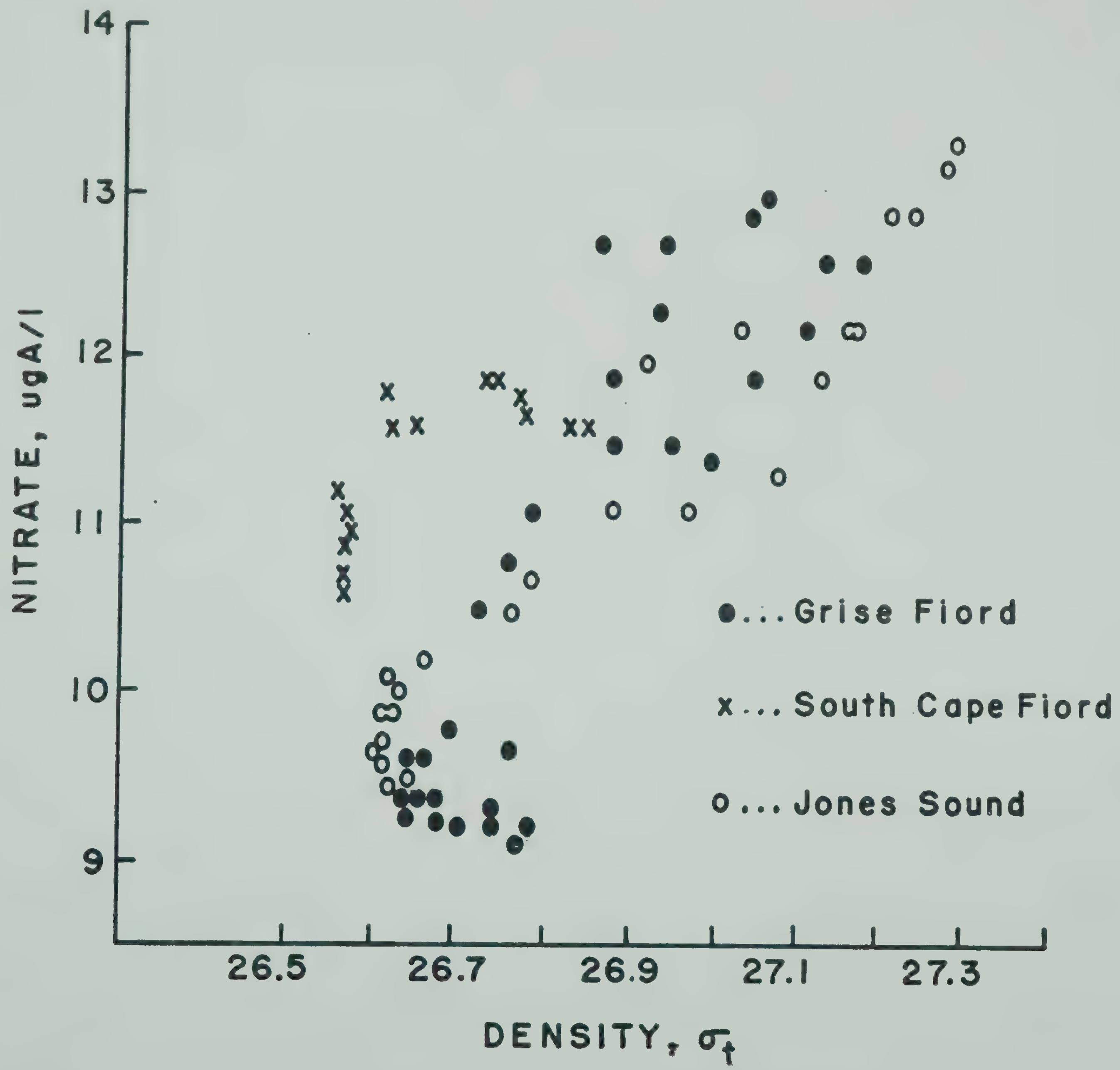

85°
84°
83°
76°30'
ELLESMERE
ISLAND
glacier
South
Cape
Fiord
Grise
Fiord
1
2
3
4
5
6
7
8
9
5
0
5
10
Nautical Miles
4
Station
JONES SOUND
King Edward VII Pt
ARCTIC OCEAN
ELLESMERE
ISLAND
DEVON ISLAND
Map
Area

FIGURE 2

Vertical air photograph of the northern end of South Cape Fiord, Ellesmere Island, NWT, showing three glaciers entering the fiord. (Photo No. A-16722-10 courtesy National Air Photo Library, Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa.)

FIGURE 3

The relation of dissolved inorganic nitrate (μg A/l) to density (σ_t) in waters off Southern Ellesmere Island, NWT, May 1969.



NITRATE, ugA/l
14
13
12
11
10
9
26.5
26.7
26.9
27.1
27.3
DENSITY, σ_t
●... Grise Fiord
x... South Cape Fiord
o... Jones Sound

TABLE 1

Oceanographic data from the waters
off southern Ellesmere Island,
NWT, May, 1969.

Station 1, Grise Fiord
May 6, 1969

Depth (m)	Temp. (^{o}C)	Salinity (o/oo)	Density (σ_t)	Nitrate	Phosphate (μg-A/l)	Silicate (a)	Silicate (b)
2	-1.39	33.220	26.745	9.3	1.23	13.6	16.0
6	-1.40	33.221	26.746	9.2	-	19.4	21.2
11	-1.43	33.247	26.767	9.3	1.18	15.2	
20	-1.58	33.247	26.772	9.1	1.18	15.0	

Station 2, Grise Fiord

May 6, 1969

Depth (m)	Temp. (^{o}C)	Salinity (o/oo)	Density (σ_t)	Nitrate	Phosphate (μg-A/l)	Silicate (a)	Silicate (b)
1	-1.66	33.130	26.704	9.2	1.18	23.4	
6	-1.64	33.124	26.673	9.3	1.14	21.0	
10	-1.73	33.130	26.679	9.2	1.19	15.0	
25	-1.70	33.145	26.692	9.8	1.13	13.3	
50	-1.35	33.223	26.768	10.8	1.20	12.5	14.8
75	-1.05	33.386	26.870	12.7	1.20	17.8	24.1
98	-1.08	33.486	26.950	12.7	1.24	20.0	20.9
123	-0.98	33.616	27.053	12.9	1.20	17.2	18.3

Station 3, Grise Fiord

May 6, 1969

Depth (m)	Temp. (^{o}C)	Salinity (o/oo)	Density (σ_t)	Nitrate	Phosphate (μg-A/l)	Silicate (a)	Silicate (b)
1	-1.75	33.109	26.663	9.6	1.18	15.4	
6	-1.76	33.101	26.656	9.4	1.23	17.8	
10	-1.65	33.085	26.642	9.3	1.24	13.7	15.8
25	-1.71	33.109	26.662	9.4	1.25	14.2	
30	-1.24	33.283	26.791	11.1	1.25	23.9	
75	-1.14	33.406	26.888	11.9	1.30	17.7	19.2
100	-1.08	33.477	26.942	12.3	1.27	19.0	20.1
150	-0.89	33.650	27.077	13.0	1.30	19.2	15.9
200	-0.80	33.733	27.140	12.6	1.19	15.6	

Station 4, Grise Fiord

May 7, 1969

Depth (m)	Temp. (^{o}C)	Salinity (o/oo)	Density (σ_t)	Nitrate	Phosphate (μg-A/l)	Silicate (a)	Silicate (b)
3	-1.82	33.077	26.638	9.5	1.23	13.6	17.8
6	-1.76	33.084	26.643	9.6	1.19	15.4	16.7
10	-1.64	33.084	26.641	9.5	1.29	15.0	16.8
25	-1.58	33.095	26.649	9.4	1.25	12.0	11.1
50	-1.33	33.206	26.732	10.5	1.22	14.2	16.9
75	-1.06	33.411	26.885	11.5	1.22	15.6	
100	-1.12	33.489	26.953	11.5	1.17	15.4	
125	-1.07	33.552	27.001	11.4	1.17	15.6	
150	-0.96	33.616	27.052	11.9	1.18	16.0	
175	-0.91	33.697	27.115	12.2	1.13	21.0	17.6
200	-0.93	33.782	27.184	12.6	1.15	15.4	

Station 5, South Cape Fiord
May 8, 1969

Depth (m)	Temp. (°C)	Salinity (o/oo)	Density (σ_t)	Nitrate	Phosphate (µg-A/l)	Silicate	
						(a)	(b)
2	-1.74	32.994	26.570	10.6	1.24	16.6	18.1
5	-1.72	33.078	26.574	10.8	1.18	15.0	19.4
10	-1.69	32.999	26.574	11.1	1.23	15.6	
25	-1.55	33.063	26.622	11.6	1.30	33.2	26.0
50	-1.31	33.221	26.743	11.9	1.25	25.0	28.5
75	-1.20	33.335	26.832	11.6	1.15	15.2	17.3

Station 6, South Cape Fiord
May 9, 1969

Depth (m)	Temp. ($^{\circ}C$)	Salinity (o/oo)	Density (σ_t)	Nitrate	Phosphate (μg-A/l)	Silicate	
						(a)	(b)
2	-1.68	32.977	26.555	11.2	1.26	15.0	20.1
5	-1.70	32.986	26.563	11.1	1.26	16.6	17.5
10	-1.75	32.983	26.561	10.9	1.23	18.0	
25	-1.55	33.054	26.615	11.8	1.24	17.8	20.1
50	-1.13	33.263	26.772	11.8	1.20	19.0	
60	-1.12	33.284	26.788	11.7	1.23	17.7	

Station 7, South Cape Fiord

May 9, 1969

Depth (m)	Temp. (^{o}C)	Salinity (o/oo)	Density (σ_t)	Nitrate	Phosphate (μg-A/l)	Silicate	
						(a)	(b)
2	-1.70	32.991	26.568	10.7	1.20	22.2	25.7
5	-1.55	32.992	26.564	10.6	1.19	16.0	18.1
10	-1.41	33.010	26.575	10.8	1.20	18.0	
25	-1.35	33.106	26.652	11.6	1.29	15.6	19.7
50	-1.18	33.217	26.734	11.9	1.23	25.0	29.7
74	-1.11	33.373	26.860	11.6	1.19	17.8	17.0

Station 8, Jones Sound
May 12, 1969

Depth (m)	Temp. (^{o}C)	Salinity (o/oo)	Density (σ_t)	Nitrate	Phosphate (μg-A/l)	Silicate (a)	Silicate (b)
3	-1.74	33.084	26.643	9.6	1.19	18.9	17.4
6	-1.68	33.061	26.623	9.9	1.24	15.3	
11	-1.69	33.058	26.621	10.1	1.20	17.6	16.7
25	-1.67	33.054	26.617	9.9	1.23	15.4	16.6
50	-1.49	33.115	26.662	10.2	1.22	16.3	
75	-1.31	33.280	26.791	10.7	1.23	16.0	18.2
100	-0.99	33.455	26.923	12.0	1.24	14.0	16.5
125	-0.89	33.599	27.039	12.2	1.20	23.9	27.3
150	-0.91	33.726	27.137	11.9	1.10	29.7	19.6
175	-0.76	33.756	27.161	12.2	1.19	16.1	21.8
200	-0.55	33.879	27.248	12.9	1.08	14.8	15.8
225	-0.47	33.932	27.288	13.2	1.10	17.8	18.4

Station 9, Jones Sound
May 14, 1969

Depth (m)	Temp. (^{o}C)	Salinity (o/oo)	Density (σ_t)	Nitrate	Phosphate (µg-A/l)	Silicate	
						(a)	(b)
2	-1.62	33.043	26.607	9.6	1.23	15.4	
5	-1.59	33.052	26.612	9.6	1.25	14.2	16.5
10	-1.63	33.056	26.613	9.7	1.24	15.5	
25	-1.65	33.059	26.621	9.4	1.25	15.2	16.6
50	-1.51	33.077	26.631	10.0	1.25	15.4	17.4
75	-1.32	33.247	26.764	10.5	1.24	21.7	
100	-1.11	33.398	26.880	11.1	1.20	21.8	
125	-1.05	33.523	26.978	11.1	1.17	21.0	
150	-1.09	33.647	27.081	11.3	1.13	12.4	16.0
168	-0.74	33.761	27.161	12.2	1.16	15.4	17.7
193	-0.53	33.842	27.218	12.9	1.18	31.3	
218	-0.42	33.949	27.299	13.6	1.15	23.0	26.4

TABLE 2

Variations in nutrient concentrations in the euphotic zone of Jones Sound, NWT, 1962.

	Maximum spring concentration	Post-bloom (midsummer) concentration	Percent reduction
	(μg A/l)		
Nitrate	10 - 11	0	100
Silicate	28 - 30	2 - 3	90
Phosphate	1.2 - 1.3	0.50 - 0.55	58